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ABSTRACT

This study compared cardio-respiratory responses during maximal arm work using a Monarch Model 880 Rehab Trainer to cardio-respiratory responses during maximal leg work on a Monarch Model 850 Bicycle Ergometer. Subjects for the investigation were 17 male university students ranging from 18 to 28 years of age. The specific variables compared included submaximal and maximal heart rate, maximum oxygen consumption, maximum oxygen pulse, pulmonary ventilation, ventilatory equivalent, and mean recovery heart rate. Each subject was tested during arm and bike work. A repeated analysis of variance indicated significantly higher values for maximum oxygen consumption, maximum pulmonary ventilation, maximum oxygen pulse, and maximum heart rate during bicycle ergometry. The ventilatory equivalent was significantly lower during bike work while the mean recovery heart rate during arm work was significantly lower than during bike work. There was no significant difference in submaximal heart rates between the groups. Reasons for the results are discussed. (JD)

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CARDIO-RESPIRATORY RESPONSES TO MAXIMAL WORK DURING ARM AND BICYCLE ERGOMETRY

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ABSTRACT

CARDIO-RESPIRATORY RESPONSES TO MAXIMAL WORK DURING ARM AND BICYCLE ERGOMETRY.

The purpose of this study was to compare cardio-respiratory responses to maximal work on an arm ergometer (Monark Model 880) and bicycle ergometer (Monark Model 850). Healthy male college students (N=17) were used as subjects. The arm ergometry protocol consisted of submaximal and maximal phases with a 10 minute rest interval between phases. Submaximal test loads were 75, 150, and 300 kgm min^{-1}, with a duration of 2 minutes per stage and a rate of 50 rpm. The initial load for the maximal test was selected according to the subjects HR response during the submaximal test and the load was sequentially increased every two minutes by 150 kgm min^{-1} until the subject could no longer keep pace with the metronome. The bicycle erogometry protocol included a 6 minute submaximal phase with loads of 150, 300, and 450 kgm min^{-1}, respectively. The initial load for the maximal test was determined by the HR response to the submaximal test and the load was sequentially increased by 150 kgm/min every two minutes at a rate of 50 rpm until the subject could not continue. HR was recorded from the ECG during the last 10 seconds of each minute. Oxygen uptake was monitored continuously during the maximal tests using a Beckman MMC. A repeated measures ANOVA indicated significantly greater values ($p < .05$) for HR max, VO_2 max, V_E max, and O_2 pulse max (differences of 5%, 26%, 14%, and 27% respectively) during bicycle ergometry. Significantly higher values were recorded for V_E/VO_2 max (25%) during arm ergometry.

The volume of oxygen consumed during physical exercise is dependent upon the workload on the muscles and on the mass of muscles at work (1). Previous authors have reported maximum oxygen consumption during treadmill running to be from 6 to 15 percent greater than for maximal oxygen uptake obtained during bicycle ergometry (8,12). Likewise, various combinations of combined arm and leg work (such as treadmill running while simultaneously engaging in arm cranking) have shown higher oxygen uptake values than treadmill running alone (6,14,15,16). Asmussen and Hemmingsen (1) have demonstrated that work with the legs can bring the metabolism to a higher level than can exercise with the arms. Previous authors have reported oxygen uptake achieved during maximal arm exercise to be about two-thirds of the maximum oxygen uptake obtained during treadmill running and cycling (1,3,17). These findings support the hypothesis that maximal oxygen consumption is directly influenced by the total muscle mass employed to produce work (2,18). Arm ergometry represents a potential aerobic exercise mode for improving the cardio-respiratory fitness of paraplegics (13). Standard procedures for arm stress testing and exercise prescription have not been established.

The Monarch Model 880 Rehab Trainer manufactured specifically for arm work is proported by the manufacturer to have less internal resistance than previous bike ergometers which were modified for arm work. Previous studies comparing the metabolic cost of arm and leg work were conducted using bike ergometers modified for arm work.

The purpose of this study was to compare cardio-respiratory responses during maximal arm work using a Monarch Model 880 Rehab Trainer to cardio-respiratory responses during maximal leg work on a Monarch Model 850 Bicycle Ergometer.

METHODS

Subjects for the investigation were seventeen male university students ranging in age from 18 to 28 years ($\bar{X}$=22.4yrs). All subjects received medical clearance for participation in the study and signed informed consent was obtained.

The specific variables compared included submaximal and maximal heart rate, maximum oxygen consumption, maximum oxygen pulse, pulmonary ventilation, ventilatory equivalent and mean recovery heart rate. Each subject was tested during arm and bike work. The testing order was randomized. During the arm ergometry test, the subjects were seated with the legs crossed and bound and the arm ergometer was positioned such that the rotary mechanism of the ergometer was horizontal to the gleno-humeral joint and at a sufficient distance to allow full extension of the arms during cranking. The arm ergometry test protocol consisted of submaximal and maximal phases with a 10 minute rest interval between phases. Submaximal test loads were 75, 150, and 225 kgm/min, with a duration of 2 minutes per stage and a cranking rate of 50 revolutions per minute. The initial load for the maximal test was selected according to the subjects heart rate during the submaximal test, so that the overall duration of the maximal test would be from five to eight minutes. During the maximal test, the load was sequentially increased every two minutes by 150 kgm/min until the subject could no longer keep pace with the metronome. Recovery heart rate was monitored for five minutes post exercise as the subjects remained seated.

The bicycle ergometry test included a six minute submaximal phase with loads of 150, 300, and 450 kgm/min followed by a 10 minute rest interval. The initial load for the maximal test was determined by the heart rate response to the submaximal test again so that the overall duration would be from five to eight

minutes. The load was sequentially increased by 150 kgm/min at a rate of 50 revolutions per minute until the subject could not keep pace with the metronome. Recovery heart rate was monitored for five minutes post exercise as the subject remained seated.

Heart rate was determined from a bipolar chest lead arrangement during the final ten seconds of each minute using a Beckman Model R.511A Dynograph Recorder. Oxygen uptake was monitored continuously during the maximal tests using the Beckman Metabolic Measurement Cart. A 16 percent O_2 and 4 percent CO_2 verified calibration gas was used to calibrate the Beckman OM-11 O_2 and LB-2 CO_2 analyzers, respectively.

RESULTS

A repeated measures analysis of variance indicated significantly higher values for maximum oxygen consumption, maximum pulmonary ventilation, maximum oxygen pulse and maximum heart rate during bicycle ergometry. The ventilatory equivalent was significantly lower during bike work while the mean recovery heart rate during arm work was significantly lower than during bike work. Finally, there was no significant difference in submaximal heart rates between the two groups (See Table 1).

DISCUSSION

An analysis of the data in Table 1 shows that maximum heart rate during bike work was approximately five percent higher than during arm work. This finding is in agreement with previous studies by Bergh, Kanstrup, and Ekblom (6) and Astrand and Saltin (3). However, the maximum heart rate during arm work was slightly higher (+2 BPM) in the present study than that reported by previous

authors. The submaximal heart rates in the present study were not significantly different. Although this finding is in agreement with previous studies, one should remember that the workload during the submaximal bike work was double the comparable submaximal arm workload.

Previous authors have reported maximum oxygen consumption ($\dot{V}O_2$ max) during arm ergometry to be from 20 to 40 percent lower than maximum oxygen consumption during leg work (1,3,17); however, Gollnick and others (10) have reported a mean difference of only three percent in competitive canoeists. In the present study, the $\dot{V}O_2$ max during arm work was approximately 31 percent less than during bike work. The subjects in the present study were not highly conditioned. The large difference in $\dot{V}O_2$ max between arm and leg ergometry may reflect the relative degree of conditioning for the subjects between the upper and lower extremities. The degree of conditioning of the arms could effect the oxidative capacity, total muscle mass, or both.

Maximum pulmonary ventilation in the current study was 16 percent higher during bike work than arm work, while the ventilatory equivalent during arm work was 20 percent higher than during bike work. Since the ventilatory equivalent is a measure of the ratio of the volume of inspired air to the oxygen consumed, one would expect the ratio to be higher during arm work since 31 percent less oxygen was consumed during arm work.

Mean recovery heart rate calculated for five minutes post exercise was significantly lower following arm exercise. Since a significantly lower mean maximal heart rate was obtained for arm work, a faster recovery would be expected.

Bergh, Kanstrup and Ekblom (6) as well as others (14,15,16) have shown that higher maximum oxygen consumptions can be obtained during combined arm and leg work compared to leg work alone, while Hermansen and others (12) have shown that max $\dot{V}O_2$ can be increased during treadmill running by the addition of arm work. These results as well as the results of the current study support the hypothesis that $\dot{V}O_2$ max is dependant on the exercising muscle mass. However, the results of Gollnick (10) showing a difference of only three percent in $\dot{V}O_2$ max between arm and leg work for competitive canoeist seems to indicate that the maximum $\dot{V}O_2$ during arm work is somewhat dependant upon the specific level of conditioning in the muscle mass involved.

Stenberg and others (17) have shown that during arm work the total peripheral vascular resistance is high and a high blood pressure is noted at a given oxygen consumption and cardiac output. Clausen and others (9) have reported that both arterial blood pressure and total peripheral resistance during heavy arm work decreases if these muscles are subjected to training. In a previous study comparing $\dot{V}O_2$ max during arm, leg, and combined arm and leg work, other authors reported large differences (2.5 - 3.0 $l \cdot min^{-1}$) in comparisons between the sum of $\dot{V}O_2$ max during arm work alone plus bike work alone and that $\dot{V}O_2$ max achieved during combined arm and leg work (16).

If $\dot{V}O_2$ max were determined by muscle mass alone, these values should be approximately equal.

Although some respiratory and stabilization muscles are active during both arm and leg exercise, Secher and others (16) have shown that the oxygen uptake in these muscles is far too small to explain the 2.5 - 3.0 $l \cdot min^{-1}$ difference between combined arm and leg work and the sum of arm $\dot{V}O_2$ and bike $\dot{V}O_2$. Therefore,

as Bergh (6) states, it appears that the volume of oxygen leaving the heart is the most important factor in setting the upper limit for maximal aerobic power in exercise with large muscle groups (i.e. uphill running, arm + leg exercise) while the upper limits of aerobic power during exercise involving smaller muscle groups such as the arms may be determined by peripheral factors such as enzyme activity and local blood flow.

In summary, an evident need exist for continued study involving the metabolic cost of arm work. Reliable prediction formulas are needed for use in prescribing aerobic arm exercise programs for paraplegics and other patient groups. The Monarch Rehab Trainer Model 880 Arm Ergometer used in this study appears to be a valuable contribtion to the market as an exercise mode for training various patient groups. The cranks are easily adjustable and it can be placed on a firm table or wall. Braking effect and crank length are graduated on easily readable scales and are easy to adjust.

Table 1. Means ± standard deviations and results of repeated measures ANOVA.

VARIABLE	ARM $\bar{x}$	ARM SD	BIKE $\bar{x}$	BIKE SD
Maximum Heart Rate (bpm)	182.5	(±17.6)	*190.9	(±15.6)
Maximum Oxygen Uptake (ml/kg/min)	31.5	(± 3.0)	* 44.7	(± 5.7)
Maximum Oxygen Uptake (L/min)	2.4	(± 0.4)	* 3.4	(± 0.4)
Maximum Pulmonary Ventilation (L/min) (BTPS)	97.5	(±15.9)	*113.2	(±15.8)
Maximum Oxygen Pulse (ml/beat)	12.9	(± 2.7)	* 17.6	(± 2.2)
Maximum Ventilatory Equivalent (L/L)	42.2	(± 6.9)	* 33.7	(± 3.9)
Recovery Heart Rate (bpm)	*116.1	(±12.7)	129.5	(±13.6)
Submaximal Heart Rate (bpm)	137.2	(±16.4)	130.9	(±13.3)

*Significant at α = .05 level with (1,16) df

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